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Mars 2020 EDL System Test Design & Progress

International Planetary Probe Workshop

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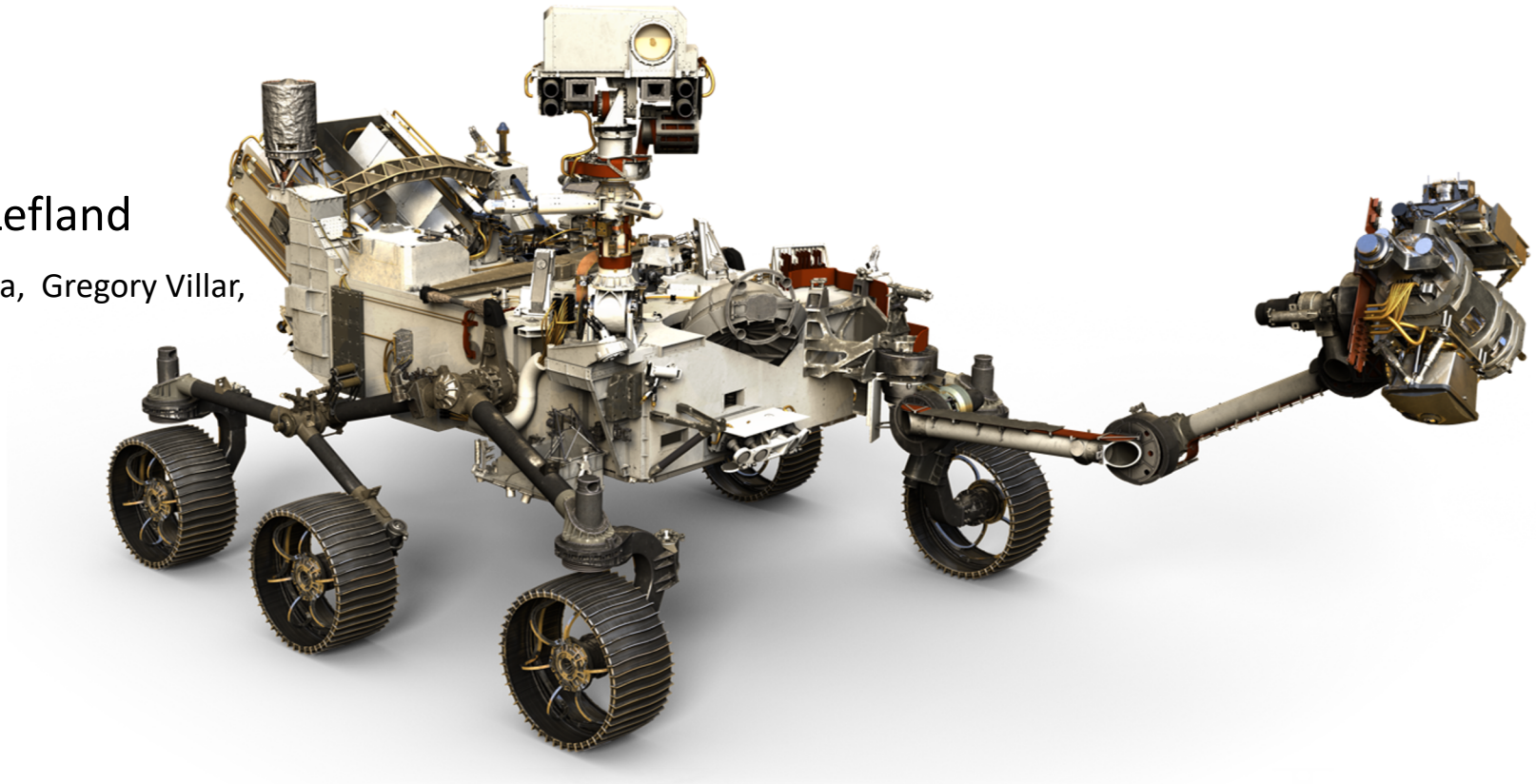
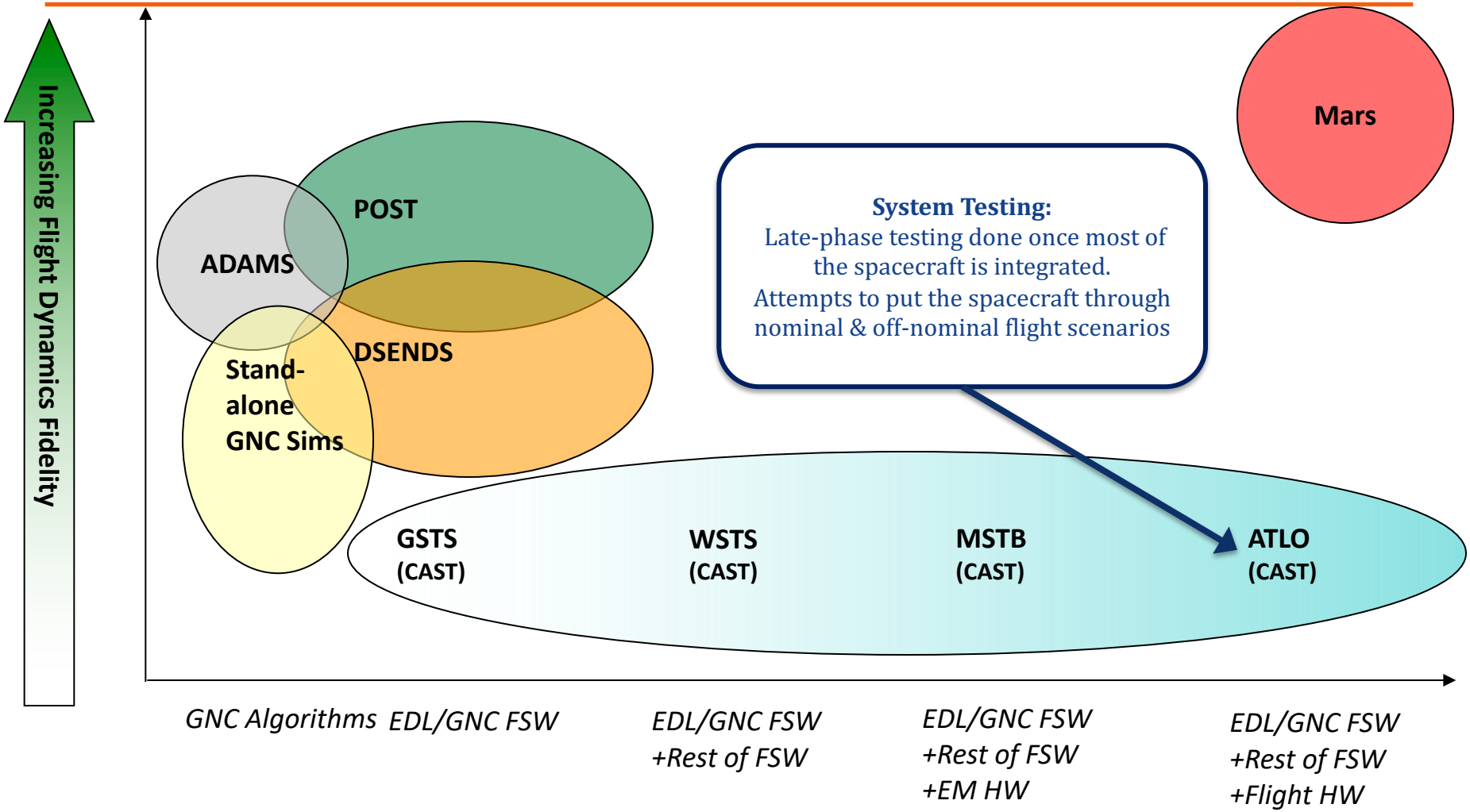


Executive Summary

- System tests are often the highest fidelity option to close out verification and validation objectives on an integrated spacecraft
- The first EDL System Test executed on Mars 2020 effectively achieved pre-launch through surface transition
- Design System Tests to be modular or preplan rework options to allow for flexibility when testing
- Create a test plan that combines nominal and off-nominal scenarios
  - Nominal scenarios that represent the in-flight capabilities the spacecraft will be expected to perform
  - Off-nominal scenarios that cover the most likely fault conditions

EDL V&V Venue Decomposition



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EDL System Test Objectives

- Overall validation of the flight system
  - Testing in the closest environment we have on Earth is our best opportunity to find issues with interactions between hardware and software
  - Marching the spacecraft through all mission phases in a flight-like manner allows the team to catch issues that could propagate between different phases of the mission that would be difficult to find in tests performed by phase specific testing
- Choose fault scenarios most likely to occur in flight and/or utilize a variety hardware configurations
- Testbed Certification
  - Comparison of ATLO and MSTB tests allows us to certify the MSTB as a usable venue for the majority of our V&V program
  - We must do equivalent tests in both venues for the best comparison, benefits to doing a test setup that we execute most often in the MSTB

Overall EDL System Test Plan

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Test ID	Scheduled	FSW	EDL Activities	Comments
ST-1	January 2019	C4	Nominal & Off-nominal Scenarios (4 total)	Aeroshell not present again until KSC after this test
ST-3a	August 2019	C4.x	Nominal & Off-nominal Scenarios (4 total)	After stacked TVAC After late integration & rework cycle
ST-5a	November 2019	C4.L	Nominal & Off-nominal Scenarios (5 total)	After STT Last opportunity for cruise & EDL in ATLO at JPL
ST-7	March 2020	C4.L	Nominal Scenarios (2 total)	Not currently in plan – potential ST that could be done at KSC Last chance to test EDL before launch

Key Benefits of System Test 1

- The forcing function to write a launch through landing procedure with a flight-like setup
- Chance to find software issues in C4, feed them forward into future software versions, and then confirm the effectiveness of the change in future System Tests
- Establishes a baseline of system performance for use as a comparison for tests performed after environmental testing and rework
- Nominal scenario runs allow work to begin on EDL MSTB Certification

System Test 1 EDL – Plan

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Runs fall into two main categories

Long, complex, multiple teams required

Short, relatively simple, only EDL team required

	1: Nominal Scenario	2. Off-nominal Scenario	3. Nominal Jumpstart	4. Off-nominal Jumpstart
ATLO time required	Multiple days	Multiple days	One day	One day
Teams Required	LCA, EDL	LCA, EDL, Fault Protection	EDL	EDL
Mission Phases	All	All	Skip to Cruise, Skip most of Approach	Skip to Cruise, Skip most of Approach
EDL Attitude	Using Cruise ACS	Using Cruise ACS	Jumpstart	Jumpstart

System Test 1 EDL – Plan

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	1: Nominal Scenario	2. Off-nominal Scenario	3. Nominal Jumpstart	4. Off-nominal Jumpstart
ATLO time required	Multiple days	Multiple days	One day	One day
Teams Required	LCA, EDL	LCA, EDL, [illegible] Protection	EDL	EDL
Mission Phases	All	All	[illegible] Cruise, Skip most of Approach	[illegible] Cruise, Skip most of Approach
EDL Attitude	Using Cruise ACS	Using Cruise ACS	Jumpstart	Jumpstart
Faults	none	11 faults through EDL phases: many hardware swaps in the days before EDL, Computer swap	[illegible]	[illegible] leads to an MSL-style divert
EDL Atmosphere	Nominal	Nominal	[illegible]	Long
Hardware primeness during EDL	All A-side	Mix	[illegible]	[illegible]
Terminal Descent Sensor (TDS)	Hardware	Hardware	[illegible]	Hardware
Vision Compute Element (VCE)	Hardware	Hardware	Hardware	Hardware

This run will provide validation for the overall system behavior from prelaunch through to landing:

- Validate the spacecraft's ability to transfer knowledge and control between mission phases
- Prove that system parameters and configurations are properly maintained and changed appropriately throughout
- Prove the impact of cruise activities have no impact on later EDL performance
- Testbed certification data

System Test 1 EDL – Plan

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	1: Nominal Scenario	2. Off-nominal Scenario	3. Nominal Jumpstart	4. Off-nominal Jumpstart
ATLO time required	Multiple days	Multiple days	One day	One day
Teams Required	LCA, EDL	LCA, EDL, Fault Protection	EDL	EDL
Mission Phases	All	All	Skip to Cruise/Skip most of Approach	Skip to Cruise/Skip most of Approach
EDL Attitude	Using Cruise ACS	Using Cruise ACS	Jumpstart	Jumpstart
Faults	none	11 faults throughout all phases: many hardware swaps in the days before EDL Computer swap during EDL	none	LVS fault leads to an MSL-style divert
EDL Atmosphere	Nominal	Nominal	Nominal	Long
Hardware primeness during EDL	All A-side	Mix	All A-side	All B-side
Terminal Descent Sensor (TDS)	Hardware	Hardware	Hardware	Hardware
Vision Compute Element (VCE)	Hardware	Hardware	Hardware	Hardware

This run provides two main objectives:

1. Show that many faults & their recoveries earlier in the mission do not impact EDL performance
2. Prove the flight hardware can successfully swap computers during EDL and Second Chance FSW can land the spacecraft
3. Faults selected throughout the test are either considered the most likely to occur or perform the most hardware/software reconfigurations

System Test 1 EDL – Plan

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	1: Nominal Scenario	2. Off-nominal Scenario	3. Nominal Jumpstart	4. Off-nominal Jumpstart
ATLO time required	Multiple days	Multiple days	One day	One day
Teams Required	LCA, EDL	LCA, EDL, Fault Protection	EDL	EDL
Mission Phases	All	All	Skip to Cruise, Skip most of Approach	Skip to Cruise, Skip most of Approach
EDL Attitude	Using Cruise ACS	Using Cruise ACS	Jumpstart	Jumpstart
Faults	none	11 faults throughout all phases, including the day before EDL, Computer swap during EDL	none	LVS fault leads to an MSL-style divert
EDL Atmosphere	Nominal	Nominal	Nominal	Long
Hardware primeness during EDL	All A-side	Mix	All A-side	All B-side
Terminal Descent Sensor (TDS)	Hardware	Hardware	Hardware	Hardware
Vision Compute Element (VCE)	Hardware	Hardware	Hardware	Hardware

This run matches closely to how many EDL MSTB tests are setup, allowing this test to be used to verify the MSTB as a reliable high-fidelity test facility.

System Test 1 EDL – Plan

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	1: Nominal Scenario	2. Off-nominal Scenario	3. Nominal Jumpstart	4. Off-nominal Jumpstart
ATLO time required	Multiple days	Multiple days	One day	One day
Teams Required	LCA, EDL	LCA, EDL, Fault Protection	EDL	EDL
Mission Phases	All	All	Skip to Cruise, Skip most of Approach	Skip to Cruise, Skip most of Approach
EDL Attitude	Using Cruise ACS	Using Cruise ACS	Jumpstart	Jumpstart
Faults	none	11 faults throughout all phases: Computer swap during EDL	none	LVS fault leads to an MSL-style divert
EDL Atmosphere	Nominal	Nominal	Nominal	Long
Hardware primeness during EDL	All A-side	Mix	All A-side	All B-side
Terminal Descent Sensor (TDS)	Hardware	Hardware	Hardware	Hardware
Vision Compute Element (VCE)	Hardware	Hardware	Hardware	Hardware

An LVS fault objective proves the system is robust to errors during EDL with this new set of hardware & software.

A long atmosphere run increases atmosphere density while staying within realistic conditions to stress both the hardware and software during EDL. The team hopes to discover any unwanted interactions from the increase of timeline duration and data collected.

System Test 1 Descopes

Prior to Test

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- Terminal Descent Sensor (TDS) and Vision Compute Element (VCE) hardware descoped prior to start of System Test, procedures were reworked in advance to run with the sensor simulations
  - Overall testbed simulation software loading with both devices hardware-in-the-loop (HWIL) led to errors in the system behavior
  - Simulations of the TDS and VCE were used during ST-1 while the software loading issue is investigated and fixed for future MSTB and ATLO tests
  - **Impact of descope**: lost four TDS/VCE HWIL tests due to this issue, which is more than a quarter of the tests originally planned. This is particularly impactful to the VCE hardware because that hardware has no MSL heritage. To reduce the risk caused by this descope, the EDL team is pushing for a change in the System Test schedule to add back some of the missing tests.

System Test 1 Descopes

During Test Execution

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- Issues with the ATLO simulation software caused problems that forced the team to cut scenarios short or restart them from the beginning, resulting in a reduction of test time to complete all 4 scenarios.
- Run 2 (Off-nominal Scenario) run was cut off during the EDL_APPROACH mission phase.
  - **Impact of descope**: lost several objectives that will become higher priorities in future tests: All B-side hardware EDL landing, Second Chance FSW EDL Landing, Landing EDL after earlier faults & recoveries
- Run 4 (Off-nominal LVS Jumpstart) run was cut from the schedule
  - **Impact of descope**: lost Long atmosphere EDL Landing, will become higher priority in future test
  - **Impact of descope**: minimal impact – because the VCE hardware had already been descoped from the System Test, this test objective was less of a priority because the fault injection would have stressed the simulation of the VCE, not the hardware itself. The EDL team will be looking to rearrange EDL_MAIN off-nominal scenarios in future system tests to incorporate this objective.

System Test 1 – As-Planned

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	1: Nominal Scenario	2. Off-nominal Scenario	3. Nominal Jumpstart	4. Off-nominal Jumpstart
ATLO time required	Multiple days	Multiple days	One day	One day
Teams Required	LCA, EDL	LCA, EDL, Fault Protection	EDL	EDL
Mission Phases	All	All	Skip to Cruise, Skip most of Approach	Skip to Cruise, Skip most of Approach
EDL Attitude	Using Cruise ACS	Using Cruise ACS	Jumpstart	Jumpstart
Faults	none	11 faults throughout all phases: many hardware swaps in the days before EDL Computer swap during EDL	none	LVS fault leads to an MSL-style divert
EDL Atmosphere	Nominal	Nominal	Nominal	Long
Hardware primeness during EDL	All A-side	Mix	All A-side	All B-side
Terminal Descent Sensor (TDS)	hardware	hardware	hardware	hardware
Vision Compute Element (VCE)	hardware	hardware	hardware	hardware

System Test 1 – As-Executed

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	1: Nominal Scenario	2. Off-nominal Scenario	3. Nominal Jumpstart	4. Off-nominal Jumpstart
ATLO time required	Multiple days	Multiple days	One day	One day
Teams Required	LCA, EDL	LCA, ~~EDL,~~ Fault Protection	EDL	EDL
Mission Phases	All	~~All~~ No EDL or Surface	Skip to Cruise, Skip most of Approach	Skip to Cruise, Skip most of Approach
EDL Attitude	Using Cruise ACS	~~Using Cruise ACS~~	Jumpstart	Jumpstart
Faults	none	11 faults throughout all phases: many hardware swaps in the days before EDL ~~Computer swap during EDL~~	none	LVS fault leads to an MSL-style divert
EDL Atmosphere	Nominal	~~Nominal~~	Nominal	Long
Hardware primeness during EDL	All A-side	~~Mix~~	All A-side	All B-side
Terminal Descent Sensor (TDS)	~~hardware~~ simulation	~~hardware~~ simulation	~~hardware~~ simulation	~~hardware~~ simulation
Vision Compute Element (VCE)	~~hardware~~ simulation	~~hardware~~ simulation	~~hardware~~ simulation	~~hardware~~ simulation

Impact of Descopes on Future EDL System Test Planning

- Consider the overall length & complexity of each standalone piece, aim for variety

  - We coupled all of the complex configuration options in the same two tests
  - ATLO realtime schedule changes left us with an awkward amount of time that did not fit any test option – we did not maximize our ATLO time

- Solutions going forward:
  - Preplan rework options to procedures that can easily change the duration of a test
  - Design standalone tests with a variety of execution times

System Test 1 Summary

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Validation Objectives Achieved

- System can successfully achieve pre-launch through surface transition, while maintaining control of the spacecraft and communication with the ground
- EDL system is capability of landing with knowledge provided by the Cruise-ACS system
- Early validation of the LVS system, as both landings flew a targeted divert
- Data for the EDL MSTB certification process

System Changes as a Result of System Test 1 Discoveries

- Fault recovery procedures: the off-nominal Scenario illuminated latent bugs left by fault protection recovery procedures
- Telecom configurations across phases: the scenarios provided data that has resulted in updated telecom configurations for improved performance across phase transitions

Conclusions

- Developing and executing a test that walks through all mission phases in a flight-like way is important to do as early as possible – even if it is not in the ATLO environment
  - All of the issues that will lead to changing flight parameters & configuration tables were discovered in the MSTB dry runs of System Test 1, not the ATLO execution
  - A majority of lower level testing will have been done by the time you are planning for a system test – but the lessons learned could have made those tests more flight-like
- Consider overall length and complexity of each standalone piece of the test plan during development. Where possible, make plans for how to handle awkward amounts of time and prepare potential rework options to fit the ever changing ATLO schedule.